PHOTOGRAMMETRY OF 3D FOOTWEAR IMPRESSIONS

FORENSIC APPLICATIONS

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A A thesis submitted in fulfilment of the requirements for the degree of

Master of Forensic Science (Professional Practice)

in

The School of Veterinary and Life Sciences

Murdoch University

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Semester 1, 2017

DECLARATION

I declare that this manuscript does not contain any material submitted previously for the award of any other degree or diploma at any university or other tertiary institution. Furthermore, to the best of my knowledge, it does not contain any material previously published or written by another individual, except where due references has been made in the text. Finally, I declare that all reported experimentations performed in this research were carried out by myself, except that any contribution by others, with whom I have worked is explicitly acknowledged.

Signed: Sean Faulkner

Dated: 25/07/2017

Acknowledgements
Associate Professor James Speers: Thank you for the time you spent assisting me when I needed help and providing me with the equipment and facilities.

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PHOTOGRAMMETRY OF 3D FOOTWEAR IMPRESSIONS

FORENSIC APPLICATIONS: A literary review

Abstract

During a forensic investigation, the recording of evidence in high detail with no distortion and limiting the loss of information is paramount. This could mean the difference between finding a possible offender or the removal of an innocent party from an investigation. Although the current method of recording three dimensional footprints records fine and minimises distortion, it still suffers from a loss of information due to the conversion of a three-dimensional subject into a two-dimensional image. Recent studies into the uses of photogrammetry has highlighted its usefulness in recording an object with high detail and little to no distortion while maximizing the amount of information retained in the three-dimensional model.

Contents

1.0 Introduction to Footwear Impressions

In the process of committing a crime the offender may leave behind a variety of forensic evidence. A common category of evidence recovered from a crime scene is impression evidence. Impression evidence covers a variety of evidence including fingerprints and footwear impressions(Bodziak, 2000; Levuen, 2005).

When a shoe makes contact upon a surface, a variety of changes could occur which may result in the creation of a footwear impression(Bodziak, 2000). Materials on the sole of the shoe can be deposited on a surface resulting in a positive impression being left behind. Similarly the soul of a shoe can remove residue from the surface upon contact creating a negative impression(Bodziak, 2000).

When the surface is soft and can deform under pressure, a shoe will cause the surface to retain the characteristics of the sole pattern. Depending on how resilient to change a surface is, the changes can be temporary or more permanent in nature. When the impression is deposited upon a nonpliable surface it is classified as a two-dimensional impression. Whereas an impression created in a pliable surface is a three-dimensional impression(Bodziak, 2000)

Footwear impression characteristics can be classified as randomly acquired or class characteristics. Class characteristics are the tread patterns generated during the (Bodziak, 2000). Class characteristics can help narrow down a suspect shoe(questioned) to a brand, type or size range of shoe.

Randomly acquired characteristics, are acquired through random occurrence. They can be the result of contact with sharp objects on a substrate which would cause something such as punctures or cuts in the sole. They could also be a result of excessive wear causing breaks or changes in the sole(Bodziak, 2017).

Besides randomly acquired characteristics, shoe impressions will exhibit general wear as they are worn. General wear is the result of the eroding away of the sole tread, as opposed to randomly acquired characteristics that are often a result of a singular event. General wear is an accumulation of events of the life of the shoe and is influenced by a variety of factors including the personal features of the wearer such as gait. As a result, the longer general wear is allowed to accumulate, the more distinct the impression (Bodziak, 2017).

Impressions recovered from a scene are compared to a person or persons of interest shoes and based upon how similar or dissimilar the comparisons are, the shoes can be assessed as the possible creator of the impression. Therefore, recovering as many impressions from a scene in the most reliable and accurate way is of immense importance as the results can have a huge influence on an investigation.

All impressions identified are photographed, as a record and analysed as evidence in an investigation. The recording for two-dimensional prints; consists of a series of photographs, the final evidential photograph is a technical scaled close-up of the print, being positioned as such removes distortion effects in the image(Bodziak, 2017). When photographing a three-dimensional photograph, the process is more complex, since the impression has depressions and ridges, light and the angle of the camera flash shadows can partially obscure the impression. To counteract this effect multiple sources of illumination can be used or multiple photos can be taken with the flash located at different points and the

photos can be compiled into one image(Bodziak, 2017). Despite using these countermeasures upon taking a photo information is still lost because a three-dimensional subject is being converted into a two-dimensional image(Bodziak, 2000; Luhmann, 2011).

2.0 Photogrammetry

Photogrammetry describes the methods used for image measurement and interpretation, in order to determine the shape and location of an object from one or more photographs(Luhmann, 2011).

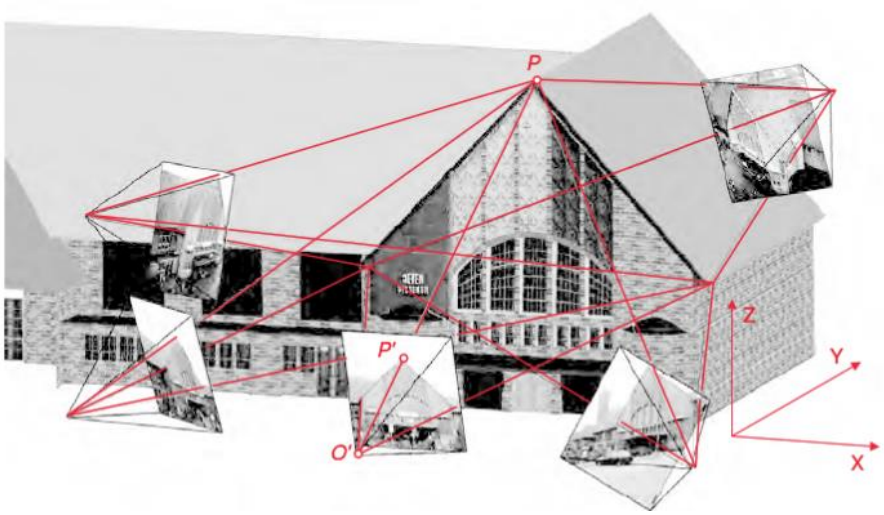

Figure 1 . *Principle of Photogrammetry (Luhmann, 2011)*

At its most basic, photogrammetry utilises Cartesian coordinates to determine the location of objects in a two-dimensional plane, by determining the relationship between the plane of the object and the camera. The image coordinate system can be extended in the z axis to allow for three-dimensional coordinates (Object points) relative to the camera.To determine the coordinates, a physical projection can be performed onto the subject, or by using a digital system, the sensor matrix can be used to define image coordinates(Luhmann, 2011).

At this stage, the subjects of the photograph have been converted into a dense cloud of object points.

The only difference between the original subject and the dense cloud is that all the points in the dense cloud have a three-dimensional coordinate attached. This allows for a representation of the subject within a model for analysis. Multiple images taken of the same subject from alternate angles results in a denser cloud and more points, as well as multiple coordinates for points, which are shared between images. This improves the accuracy and the detail of the resulting model(Luhmann, 2011)

From this point, the subjects can be geometrically reconstructed. The simplest way of performing the reconstruction is to perform triangulation between the points.

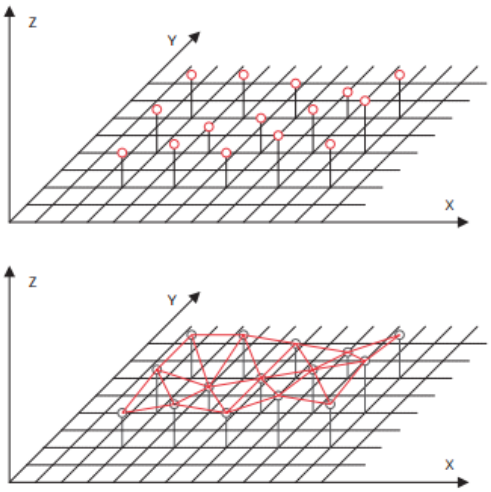

Figure 2 *Example of a 3D point cloud and resulting mesh construction(Luhmann, 2011)*

This geometric reconstruction produces a mesh for the model. While dense clouds do produce a viewable model, there is no topology relation between points hence further processing cannot be performed upon the model. The triangulation of these points allows for the processing of the model to continue beyond a point cloud(Luhmann, 2011).

2.1 Methods of Capture

The number of images used for the reconstruction of a model through photogrammetry can affect the accuracy and detail.

2.1.1 Single Image photogrammetry

The reconstruction of a three-dimensional object from a single object from a single image is possible, however, it requires additional geometric information, The accuracy of a single image reconstruction is dependent on the image scale and the ability to distinguish and measure figures within the image. Single image photogrammetry is typically applied to objects on a planar surface such as a building facade(Luhmann, 2011).

2.1.2 Stereo Photogrammetry

Stereo Photogrammetry works similarly to human vision, two images taken from slightly differing perspectives can be compiled into a single image. Due to the digital process, the limitations of human vision can be ignored when recording the images allowing for more convergent images or shifted camera positions provided there is a method to scale the images appropriately. The accuracy of image coordinates will differ depending on their location in relation to the image plane. (Luhmann, 2011)

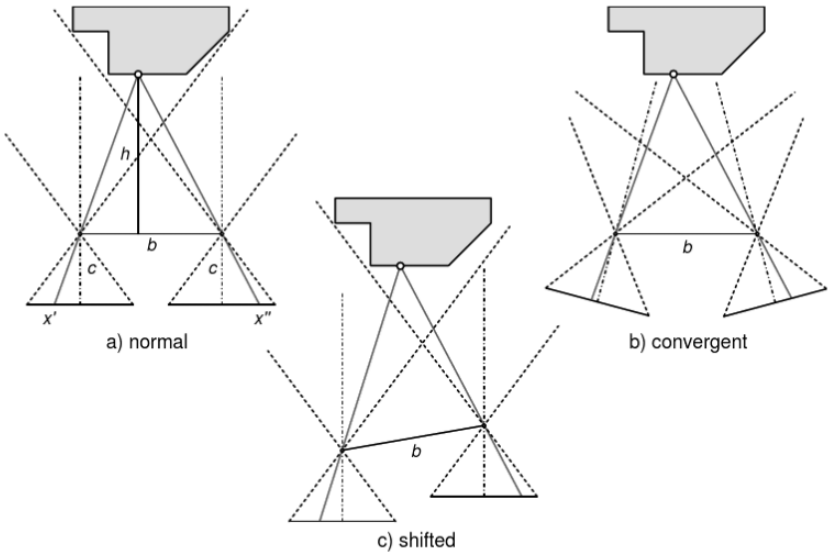

Figure 3. *Stereo image Photogrammetry Configurations(Luhmann, 2011)*

The accuracy of image coordinates will differ depending on their location in relation to the image plane.

2.1.3Multi-Image Photogrammetry

Multi-image configurations are not restricted with respect to camera position and viewing directions, the object is recorded using a substantial number of photos taken from locations chosen to enable enough intersecting ray bundles in the object space, object coordinates are determined using multi-image triangulation, if there are sufficient number of intersections, uniform accuracies in all coordinates can be obtained(Luhmann, 2011).

Multi-image is the most commonly used method for close range photogrammetry.

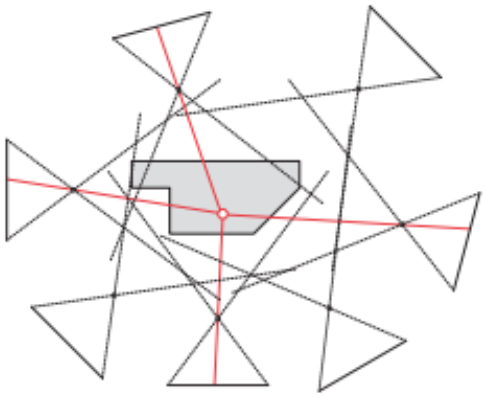

Figure 4. *Multi-image Photogrammetry (Luhmann, 2011)*

2.2 Software

There is a large selection of software on the market that can be used to create three-dimensional models through photogrammetry, the price range for the software can vary from free programs such as ARC 3D, a web service that allows for three-dimensional reconstruction of images(Levuen, 2005), to thousands of dollars for programs such as Agisoft Professional Scan and 3DF Zephyr (3DFLOW, 2013; LLC, 2010). Due to the large variation in prices the restrictions and features that each program offers will vary, each program at its most basic will produce a three-dimensional model, however, features such as the ability to scale the model or to perform in application measurements will be either restricted or non-existent in the cheaper programs, both features are extremely important if the program is going to be used for analysis of a footwear impression in a forensic investigation.

With the need to be able to scale and perform measurements within the program, the software options are restricted to the higher end of the price range.

Both Agisoft and 3D Zephyr have similar pricings, Zephyr offers the ability to construct models from a video recording, in addition to the use of images, while Agisoft does not offer the video feature it is less resource intensive on the computer(3DFLOW, 2013; LLC, 2010).

2.2.1 Software Process Summary

Both the Zephyr software and Agisoft process for producing a model is broken up into four major steps:

The first step in the software process is to align the photos by matching common points, this also allows for the positioning of each of the cameras by the program and misaligned cameras resulting from poor image quality can be identified and either removed or realigned. (3DFLOW, 2017; Agisoft, 2017a)

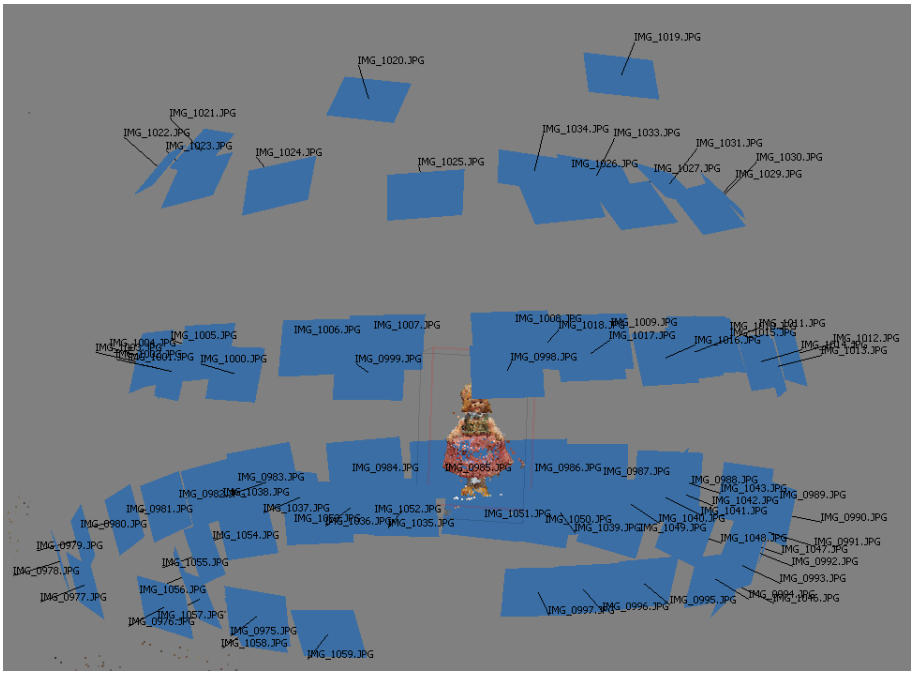

Figure 5 *Camera alignment using Agisoft Photoscan® with sampled images(Agisoft, 2017b)*

After determining the camera locations, an algorithm builds a dense point cloud by determining the image ray intersections from all the photos. At this stage, the model is in a viewable state. (3DFLOW, 2017; Agisoft, 2017a)

Figure 6 *An example of a Dense Object Point Cloud produced using Agisoft Photoscan® with sampled images(Agisoft, 2017b)*

After determining all the object points, the next step in the process is for the algorithm to construct a mesh of the object by triangulating between all the object points, the mesh smooths out the noisy point cloud allowing for a better representation of the object, the mesh also allows for additional editing of the object allowing for the last step. (3DFLOW, 2017; Agisoft, 2017a)

Figure 7 *Agisoft sample with mesh applied model has been smoothed and has less noise present when compared to Figure 6*

The last step in the process is to apply a texture to the mesh, the texture adds a finer amount of detail to the model allowing a for a clearer object and more defined object surfaces and edges. (3DFLOW, 2017; Agisoft, 2017a)

Figure 8 *Agisoft sampled model with applied texture, there is an increased detail when compared to Figure 7*

While it is possible to measure models using the program after generating the dense cloud in the second step proceeding through the entirety of the process cleans up the model which is helpful when fine detail is needed to properly assess a model such is the case when the model is being used in an investigation. (3DFLOW, 2017; Agisoft, 2017a)

3.0 Close-Range Photogrammetry (CRP) Studies

As CRP only requires software to compile photos into a three-dimensional model, this technique can be applied to a multitude of disciplines and scenarios(Luhmann, 2011), some recent examples include the use of photogrammetry to reconstruct a ceramic pot from fragments found at an archaeology site(Barreau et al., 2014). While the generation of the mesh for each of the fragments was successful, difficulties were encountered when combining each of the fragments into a single object due to the size of some of the fragments recovered(Barreau et al., 2014)

CRP was explored as a less invasive way of determining basic information on status and distribution of animal populations by generating three-dimensional models of pawprints left by lions (Marchal, Lejeune, & Bruyn, 2016). It was found that despite some issues around some of the reconstruction parameters, after some calibration and optimization the modelling showed promise with an increased reliability of two-dimensional photos.The study noted that due to the requirement of taking multiple photos from differing angles, negated the distortion effects of two-dimensional photos when taken at an incorrect angle (Marchal et al., 2016)

A recent thesis exploring various options for three-dimensional mapping for forensics, explored the use of photogrammetry as one of the possible options (Colwill, Murdoch University. School of, & Life). According to their findings, out of the options explored, photogrammetry was able to generate the most detailed and accurate models, the paper noted that the footwear impression examined was of particularly high detail.

4.0 Experimental Aims and Hypothesis

Recent studies have demonstrated the potential of three-dimensional photogrammetry for use as a forensic tool. To assess photogrammetry as a viable option for forensics the project will assess three criteria.

1. The first requirement is that the model produced from captured images by Agisoft Photoscan® software is sufficiently accurate, if the impressions are not accurately represented by the model then the model cannot be used as evidence. To assess this the length and width of the impression models will be measured and compared with the actual measurments of the shoe sole to see if there is a significant difference between the two

Commented [JS1]: How are you assessing the accuracy?

2. The models need to be assessed for distortions present in a model would again be rendered unusable in an investigation as evidence. By including a object with known dimensions such as a an L scale, distortions in the produced model will alter those known dimensions.
3. The quality of the models produced by the agisoft software need to be assessed. This can be done by comparing visible impression charcterisitcs contained with in the agisoft models, depending on the quality of the model finer detail on the characteristics could be either visible or blurred.

In addition to assessing the above criteria, the study aims to find the best way to record photos to use in the generation of a three-dimensional model. Aspects that need to be tested include whether having a tripod at fixed angles taking the photos results in a more reliable model when compared to a model created from photos taken by hand and the effect that camera height has on the models produced by the Agisoft Photoscan® software.

5.0 Conclusion

The potential of photogrammetry in the fields of forensics needs to be explored further, with a focus on three-dimensional footwear capture and analysis. Studies have demonstrated that the Agisoft Photoscan® software can record impressions(Colwill et al.; Marchal et al., 2016). Photogrammetry still needs to be assessed to see how viable it is as a forensic tool, in addition no study has been conducted to conclude the best method to record photographs for photogrammetric use in a forensic context, although a study has found that increasing the number of photos increased the accuracy of the resulting model(Marchal et al., 2016). During an investigation at a crime scene, time is an important factor, therefore a balance needs to found between generating a high-quality model that can be used as evidence and the amount of time spent recording photographs.

Commented [JS2]: What models?

Commented [JS3]: How are you going to assess the distortion?

Commented [JS4]: Again what moel?

Commented [JS5]: How are you going ot assess clarity?

Commented [JS6]: How?

Commented [JS7]: This needs ot be in your aims and objectives.

Commented [JS8]: What software? Think of your audience – they need to be given details.

It has been determined that multiple camera shots at differing angles and positions improve accuracy (Marchal et al., 2016) but it has yet to be determined whether having a tripod at fixed angles taking the photos results in a more reliable model when compared to a model created from photos taken by hand. In the same vein for quality versus time, if more photos can be generated using a lower definition camera produce a model like that of a high definition camera with fewer shots.

Commented [JS9]: This needs ot be in your aims and objectives.

A comparison between the traditional method of compiling multiple photos from a single angle with photogrammetry is needed not only because the older method is considered the standard way of recording three-dimensional impression. Also, because the traditional method has a similar more basic method to photogrammetry, which is to compile the information presented in multiple images into a singular product.

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PART ONE

Manuscript

PHOTOGRAMMETRY OF 3D FOOTWEAR IMPRESSIONS

FORENSIC APPLICATIONS

Abstract

Three-Dimensional photogrammetry is a technique of constructing a 3D model from multiple photos. Applying photogrammetry to forensic impression analysis allows for the recording of a three-dimensional model of an impression with greater detail and a subsequent more in depth analysis of the impression. This study was to determine how viable photogrammetry was for footwear impression analysis and to determine the effect that several factors have on the impression models. The results found that while the models produced by the process can be of a high detail, however the process has issues surrounding the conditions that could be present during a scene investigation.

keywords

Forensic science, footwear impressions evidence, 3D, photogrammetry

Introduction

The current method for analysing a three-dimensional impression in a forensic investigation is to compile multiple photos into a single image. These images are taken vertical to the substrate which removes perspective analysis. A flash can be deployed at different points to illuminate the various parts of the same impression based on the raised ridges caused by the impression (Bodziak, 2017). The conversion of a three-dimensional impression into two-dimensional image causes a loss of information and detail (Luhmann, 2011). Three-dimensional photogrammetry is a method of compiling multiple images from positions around the subject into a single three-dimensional model. This holds an advantage over the current compilation method as the subject is no longer being compressed into a single image which would reduce the amount of information loss while still being free from perspective distortion effects (Luhmann, 2011).

Commented [JS10]: Forensic?

Photogrammetry is not resource intensive, requiring only a high detailed camera and the appropriate software to perform a photogrammetric analysis.

This study aims to determine the viability of three-dimensional photogrammetry as a forensic tool for three-dimensional impression capture. The study will focus on the quality of the models produced, the accuracy of the models and if there are any distortions present in the models that would prevent them from being used as evidence. In addition, the paper aims to determine if there are factors involving camera positioning and settings could improve the models produced using photogrammetry. The factors investigated were; the use of the tripod when recording the impression, the camera height has on the detail of an impression and the use of camera settings when recording an impression.

Camera settingsThe algorithm used for the construction of a three-dimensional model matches points across multiple photos to construct the impression model. As a result, the more uniform the photos are for light exposure will result in more points being matched between photos leading to a more detailed model, automatic camera adjustment is when camera settings such as shutter speed, ISO and aperture for taking photos is left up to the camera sensors and programming to decide the optimal settings, however there can be drawbacks to adjusting these settings to the extremities as the diagram below demonstrates

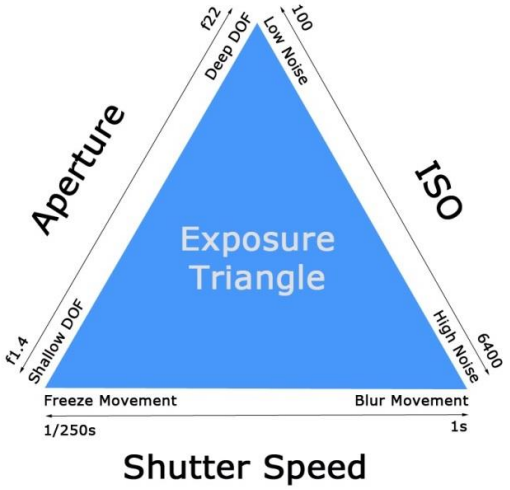


Figure 1 Camera Exposure triangle (sourced from (shine, 2016))

For example, if the shutter speed on the camera is set too slow then blur can be inadvertently being introduced into images as a result of camera shake, if this is the case less points could be picked up by the algorithm resulting in a poorer quality model. Relying on the automatic camera adjustment could increase the chance that these settings would be adjusted in a less optimal way reducing the overall image quality.

By maintaining a manual control over the exposure settings, the operator of the camera can reduce the likelihood of these settings being set in a way that has a detrimental effect on the generated model of the impression.

Tripod

The use of a tripod allows for the stabilisation of the camera this and can offer a more regulated way of controlling camera positioning, but tripods only have a limited number of heights and angles available to them thus presenting an issue when taking photos as they need to be positioned in a way so as not to disturb the impression while still having an adequate shot from multiple positions

Commented [JS11]: What where the shutter speeds used? Again think of Derek having to repeat your work – they need guidance.

Camera Height

If the camera is closer to the impression it could pick up a greater amount of detail in the impression, however if the camera is too close then it is no longer possible to record the impression in its entirety for each shot, if this is the case then to produce a model, partial images need to be used and this could result in inaccuracies when producing the full model.

Materials

The camera used was a Nikon d5500 digital SLR camera with an 18-55mm lens, the cameras flash unit was not used during the study. The software utilised for the photogrammetry analysis was Agisoft Photoscan® Professional Edition. The program was run on a Windows 10 machine the following specifications, Intel® Core™ i7-3820 CPU, NVIDIA GeForce GTX 980, Video card with 64 GB of RAM.

Commented [JS12]: What lenses did you use?

Commented [JS13R12]:

Commented [JS14]: What about the flash unit?

The footwear impressions were created using a well-worn single old Brooks Shoe size 12 US onto general builders sand.

Commented [JS15]: Grade quality – general builders sand?

Figure 2 Picture of outsole used in the experiment

Methods

An impression of the test shoe was made into levelled sand. The impression was visually examined before capturing the images to confirm that both the heel and toe of the test shoe was impressed into the sand and fine detail, such a manufacturing logos and unique features as can be seen in the figure below. If the impression was incomplete, missing the impressed words or had some form of disturbance to the impression, such as having a broken form or disturbed sand the impression would be redone until it was judged satisfactory.

Commented [JS16]: Of what?

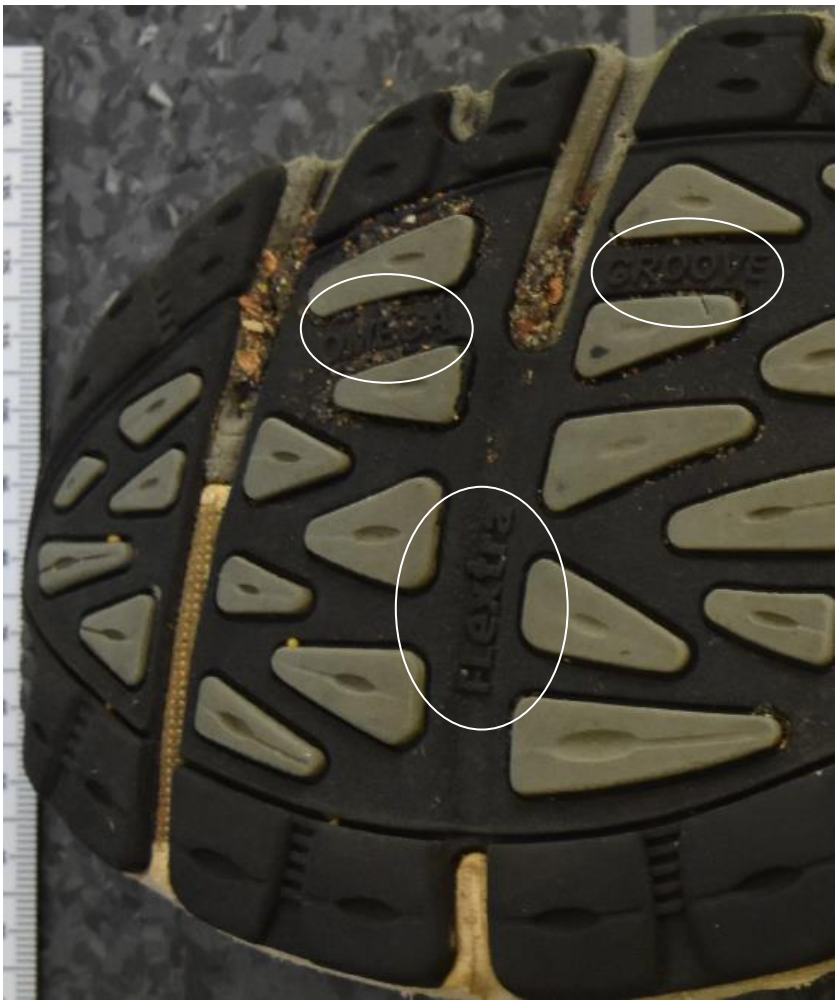


Figure 3 Words present on sole of test shoe

The photos of the impression were taken away from light sources that could directly shine upon the footwear impression, to reduce shadows being produced by the ridges present in the footwear impression.

Photos of the shoe impression were taken in a circle at points with sufficient overlap between photos to enable the construction of a 3D model using photogrammetry according to the Agisoft PhotoScan User Manual(Agisoft, 2017).

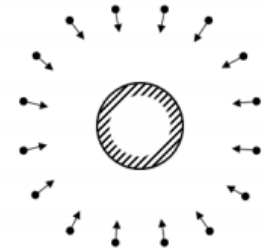


Figure 4 Method of capturing impression

If a tripod was used, the photos would be taken at the same height and angle. Similarly, If a tripod was not used then care would be taken to take photos at the same height and angle but the ability to keep these the same would not be as reliable as with a tripod.

Commented [JS17]: did you measure accurately the set points – how did you do this, how did you then relate this back to the 3D photogrammetry?

The photos were imported into Agisoft Photoscan® Professional Edition, and processed at the software's default high detail setting. Within the program, the photos underwent an initial alignment, the photos then had in program markers applied to points on the L-scale ruler within the photos. These markers allowed for the photos to be realigned for a more accurate model and by using the L-scale as a known length allowed for the measurement of the footwear impression.

Results

Model Quality

Commented [JS18]: What quality? Image Quality Photogrammetry quality?

Auto camera vs manual camera setting adjustment (ISO, Shutter speed and Aperture)

Manual control involves utilising the cameras exposure sensors to adjust the factors that regulate the light exposure of the camera manually. While this adds a human element to the process, the human element can adjust the settings that the automatic system would not based on the visual feedback from the camera display.

(a) manual camera adjustment

B)auto camera adjustment

Figure 5 Full impressions first taken with a manual setting camera adjustment and then with an automatic camera setting adjustment

Commented [JS19]: Focus adjustment?

While there appears to be no difference between the manual adjustment of camera settings and the use of the cameras automatic settings when viewing the impression models as whole, upon closer examination the manual is of a slightly higher the characteristics such as the raised circle in the centre of lower grip which has a more defined edge as can be seen in the images below

a) automatic camera settings b) manual camera settings

Figure 6 comparison of one of the characteristics in the impression the b has more defined edges when compared to a

The controlled light conditions meant that the cameras automatic process did not cause extreme settings when it came to the exposure settings, however the slight improvement in the manual process demonstrates the usefulness of manually adjusting the camera settings as it allows for a fine control of image tone between images which improves the algorithms ability to recognise points between images, which improves the model detail.

Commented [JS20]: Still need to explain what the maul process is? Focus, iso, aperture and shutter speed?

Tripod vs no Tripod

(a) Tripod

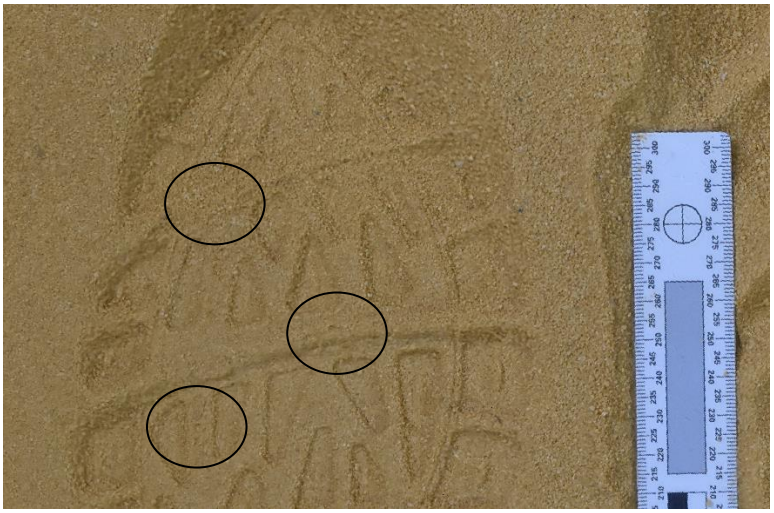
(b) No tripod

Figure 7 Models made from images using a tripod vs without a tripod

In the controlled conditions present during the test the shutter speed on the camera was fast enough to not introduce blur do to camera shake hence the models produced by the process are similar in visible characteristics, which can be seen in figures below

Commented [JS21]: As above what is the evidence for preferring one over the other or the reason for finding no difference

a)



b)

Figure 8 Closeup of impression model produced from photos taken a) without a tripod b) with a tripod

as can be seen in the above figure the characteristics are similar in appearance for example the impressed word on located in the lower most circle is visible but in both cases only a few of the letters can be identified.

While the two impression models are similar in the conditions present in the test. In a practical setting if the shutter speed needs to be slowed down to ensure that there is adequate exposure for the camera to record the images, in this case a tripod would be useful to stabilise the camera to reduce camera shake.

However as mentioned before using a tripod adds its own challenges when recording for photogrammetry as the tripod needs to be positioned around the impression without disturbing the impression or other items of interest at a crime scene.

Full shots vs Closeup/partial shots

(a) Partial

(b) Full

Figure 9 Comparison between a model made up of partial images and a model made up of full images

Comparing the two models the characteristics visible in the model composed of partial shots has a higher detail this can be seen in the figure below

a)

b)

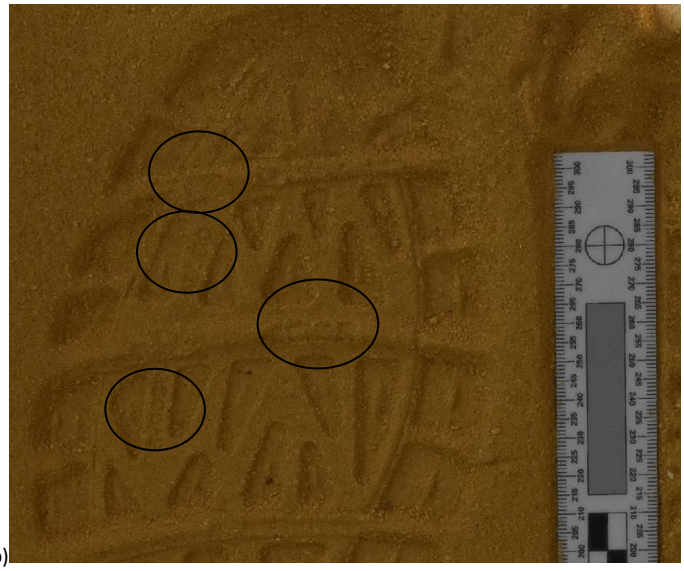


Figure 10 Closeup of a) partial b) full shot models

Commented [JS22]: Again show evidnce

As can be seen all the characteristics have improved detail over the model composed of full shots

The void in located in the uppermost circle has an increased detail showing a slight impression in the middle of it, the indented words located in the other two circles on the left also have greater detail with the lower word having all its letters being legible

The model made up of partial shots does not appear to have any inconsistencies when compared to the model made from complete shots either which is good because this means that the camera can take close images for a complete model with more detail.

Composite model

A single model was produced from many photos of differing quality including the photos from the high detailed model above to see if inferior quality can be negated.

Figure 11 A model made up of photos of varying quality

This model demonstrates the need for consistency between the composite photos as those of poorer detail will decrease the quality of the model to a large degree

Relying on the camera to decide the appropriate settings, can have negative effects on the overall clarity of the photo. By relying on the cameras sensors and programming there is an increased chance that the camera could alter the exposure settings to an extreme having an negative impact on the quality of the images captured by the camera and subsequently the model produced from those images, an example of this would be having the camera reducing shutter speed enough to introduce camera shake blur into the images. However even when this is not the case the automatic settings do not have the fine control that a manual adjustment has at keeping the tone of the photos constant, if there is too much variation in the tone between photos this throws out the programs algorithm which can lead to misaligned photos or even the failure to recognise photos are of the same subject.

By reducing the distance of the camera from the impression, the detail of the model is improved, within reason there is no limit to how close the camera can be to the impression as long as the camera is far enough away to not disturb the impression and the angle of the camera is not extreme enough to not capture the print, all that is required is the correct exposure to record the impression and sufficient overlap between images for the algorithm to align the images correctly to construct an accurate model, the only drawback decreasing the distance is that more photos are required to ensure sufficient overlap of the print and there is an increased risk of missing part of the print due to incomplete coverage when recording the impression.

Using a tripod does offer stability, however the tripod only has a finite number of angles and heights which a photo can be taken from, while the tripod does offer the ability to reduce the chance of blurring from camera shake, its restriction in height and angles means that getting the camera close to the impression close images is incredibly difficult without a

more custom tripod. Similarly, the need to manoeuvre a tripod around the impression to take photos from the required angles without disturbing the impression is incredibly difficult. This difficulty would only increase at a crime scene when there are obstructions, other impressions or exhibits that need to be left undisturbed makes a regular tripod impractical to use at a crime scene for photogrammetric work.

Accuracy

The shoe was measured using measuring tape by hand so that the curvature of the shoe was considered, the shoe was measured in both length and width. This was to see if the program had a variation accuracy measuring for length and width.

Figure 12 Shoe with lines of measurement drawn in

The length of the shoe was measure from the toe of the shoe through the middle of the sole to the heel. The width was measured across the widest part of the shoe from one grip to another

type	Length (cm)	Width(cm)
shoe	32	11.4
auto tripod	32	11.5(0.1)
manual adjustment	32.5(0.5)	11.4
manual tripod	32.7(0.7)	11.6(0.2)
Closeup photos	31.40(-0.6)	11.3(-0.1)
Full set	31.80(-0.2)	11.10(-0.2)

Table 1 The measured length and width of each impression with the difference between the generated model and the actual impression shown in brackets

Commented [JS23]: Difference in what – you need to say that the table was comparing the generated impression measurements against actual.

Besides the models displayed in the above table duplicate models were made using additional photos.

Using the measured values from all the models a two two-tailed T-tests were performed, the first test measured the differences in values between measuring in the width and length and found that there was no significant difference between the differences in the width values and the length values (p=0.05), the second test was conducted to determine if there was a significant difference between the measured values and the actual values for shoe length, this test also demonstrated there was no significant difference between the measured and the actual values.

The measured values demonstrated that even when a model is of poorer quality because of blurry images, if the in-application scale is implemented correctly measurements can still be performed with some degree of accuracy. These results also show that despite the use of only partial shots the overall model made up is no less accurate than a model made up with photos of the entire impression.

Model Defections

While examining the generated models in application appear to show no signs of perspective distortions such as converging lines, perspective distortions would most likely become apparent after creating a single image of the model as the position of the current viewing angle would reintroduce such distortions upon capture. Some of the models do appear to contain some imperfections, where the model can go from high detail to blurred detail an example of this can be seen below where details can go from having definite edges to having blurred or merged together edges.

Exporting the models out of the software and viewing in another viewer with programs such as View 3D does remove some of these imperfections and can improve the clarity of the models as the below comparison can show

a) Exported closeup model

b) Closeup model

Figure 13 Comparison between the model made up of partials in-application and the exported model

However, this exportation only serves to improve the models contrast the underlying imperfections are still there and can sometimes be enhanced by the contrast change

Figure 14 high magnification of an exported model black circles demonstrating areas of varying quality

As can be seen in the above figure there is a variation in detail in the image. This variation could be caused by a lack of overlap between images decreasing the number of points available for the algorithm, it could also cause by the distance from the impression reducing the amount of detail that can be picked up by the cameras.

While these defections do not appear to impact overall measurements as an edge can still be defined, they can cause the characteristics of the impression to be obscured due to poor detail.

Discussion

Photogrammetry does display promise as a potential forensic tool, if the scale is implemented correctly it can be used to give accurate measurements of a shoe, even when the model is less defined due to poor image quality. The software also demonstrated the

ability to capture high detail and its ability to use partial images of an object and to compile the images into a full model which is accurate and reliable. This allows for closer images to be taken and at angles that allow for finer shoe characteristics to be captured in higher detail as opposed to full shots that fail to pick up the finer characteristics.

Photogrammetry's ability to negate perspective distortions brought about by photos taken at angles, by compiling multiple images into a single dimensional model is incredibly useful, especially in forensics where images need to be neutral and free from distortions to be used as evidence.

The programs ease of use also shows promise little training is needed to produce and analyse an impression model, this is also a positive for the software as no intensive training is needed for its analytical use.

However, despite the benefits that photogrammetry offers, the study has demonstrated that photogrammetry is not useful enough to replace the current method of recording three-dimensional impressions. For example: Photogrammetry can produce highly detailed models, but even in the controlled conditions the lighting may not be consistent for the program, the uneven light has detrimental effects on the algorithm. In the best case, it is less accurate in aligning the cameras, usually this can be solved by adding markers in program and forcing the cameras to realign. In the worst case, however the program will fail to recognise a photo as belonging to the same photo set, there may be a way to resolve this issue but assuming there is not away to fix this then this could have an enormous impact on the technologies use in the field, most three-dimensional impressions would occur outside where light is less controlled, these conditions would not be optimal for photogrammetry.

If in the future advancements are made to improve the program performance when analysing photos taken in variable lighting conditions then photogrammetry might be worthwhile for use as a forensic tool, but in its current, state the software is too unreliable when faced with conditions that are likely to be present during a forensic investigation.

Another potential solution to overcome this issue would be to have a method to uniformly illuminate the impression to negate the issues presented in outdoor conditions.

If photogrammetry were to be used to examine a three-dimensional impression. Then most reliable way to get a highly detail accurate model of an impression using photogrammetry, would be to get the camera close to the impression for this paper the camera was about 30 cm away from the impression, as this distance should be a good balance between being close to the impression for high detail without be so close as to potentially miss parts of the impression due to insufficient coverage. Taking partial shots of the impression with a large overlap between photos to ensure that there are sufficient points shared between images, if there is an appropriate tripod for such a task use the tripod, however if the tripod is likely to disturb the impression or interfere with the crime scene avoid using the tripod, and to manually adjust the camera to ensure that the image tone stays as consistent as possible and to ensure that the camera exposure settings are not set to the extremities.

Conclusion

While the results demonstrated the potential of photogrammetry as a forensic tool, it can deliver a high detailed impression model which can be accurately measured with ease. The problems encountered with lighting calls into question the programs ability to cope with conditions that would present during an investigation, this problem limits photogrammetry's potential as a forensic tool. If in future if the algorithm is improved to

deal with this issue then it can indeed prove useful for impression analysis, an alternative to improving the algorithm would be to create a method to illuminate impressions in a consistent way to help to algorithm overcome its difficulties

Acknowledgements

Associate Professor James Speers: Thank you for the time you spent assisting me when I needed help and providing me with the equipment and facilities.

Disclaimer

The project was performed using Agisoft Photoscan® Professional Edition, for the conclusions of the paper it is assumed that the algorithm used in this program is going to be consistent across the other photogrammetric software.

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